

# The Space Launch System and the Pathway to Mars

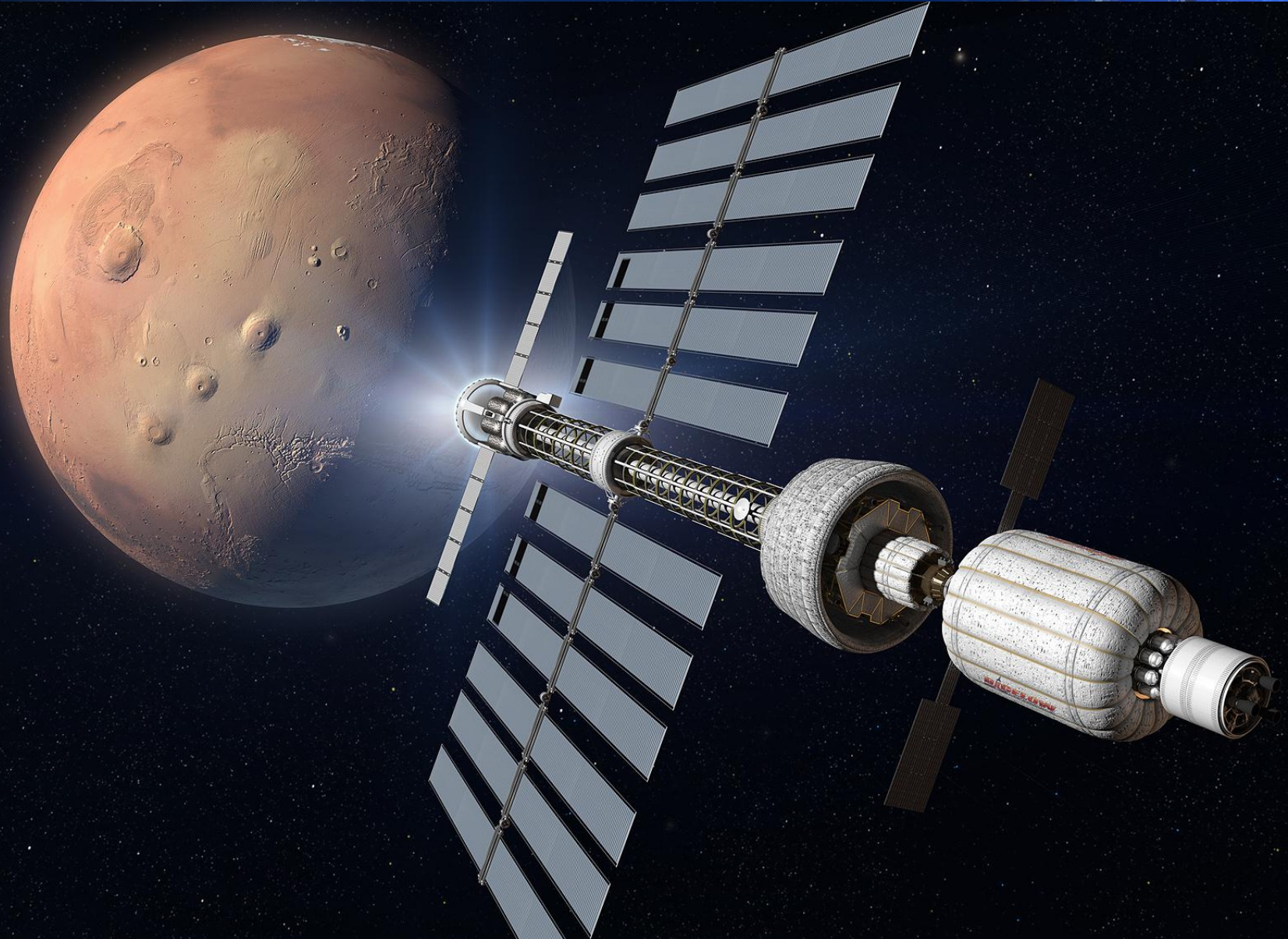
SSERVI – NASA Exploration Science Forum  
July 23, 2014





# The Ultimate Destination?

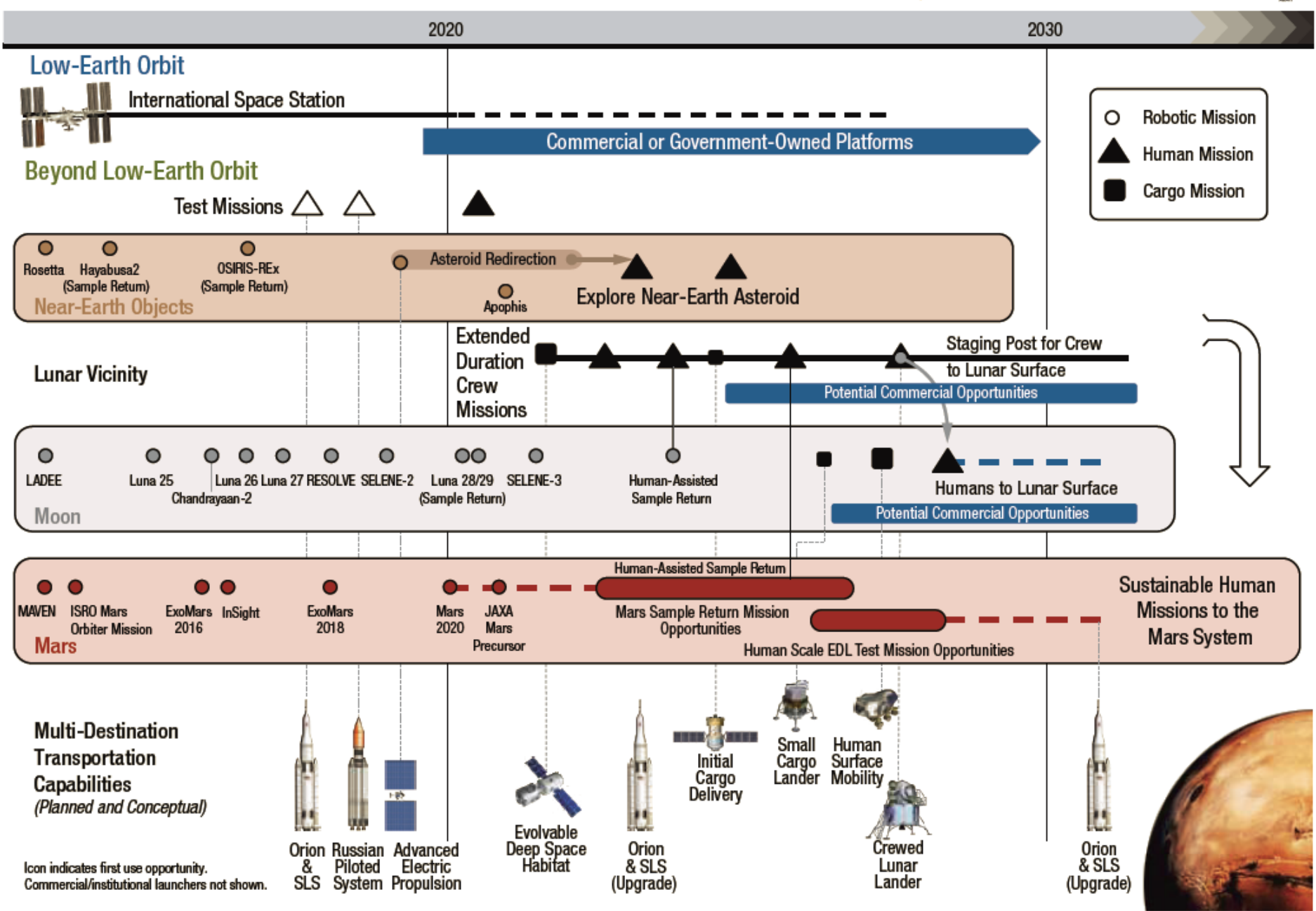
Defense, Space & Security  
Space Exploration



# Outline

- **Introduction**
- **The Global Exploration Roadmap**
- **The NRC Report – Pathways to Exploration**
- **SLS Configurations**
- **ARM**
- **Cislunar Habitat**
- **Payloads to Lunar Surface**
- **Mars Surface**
- **Final Thoughts**

# ISECG Mission Scenario

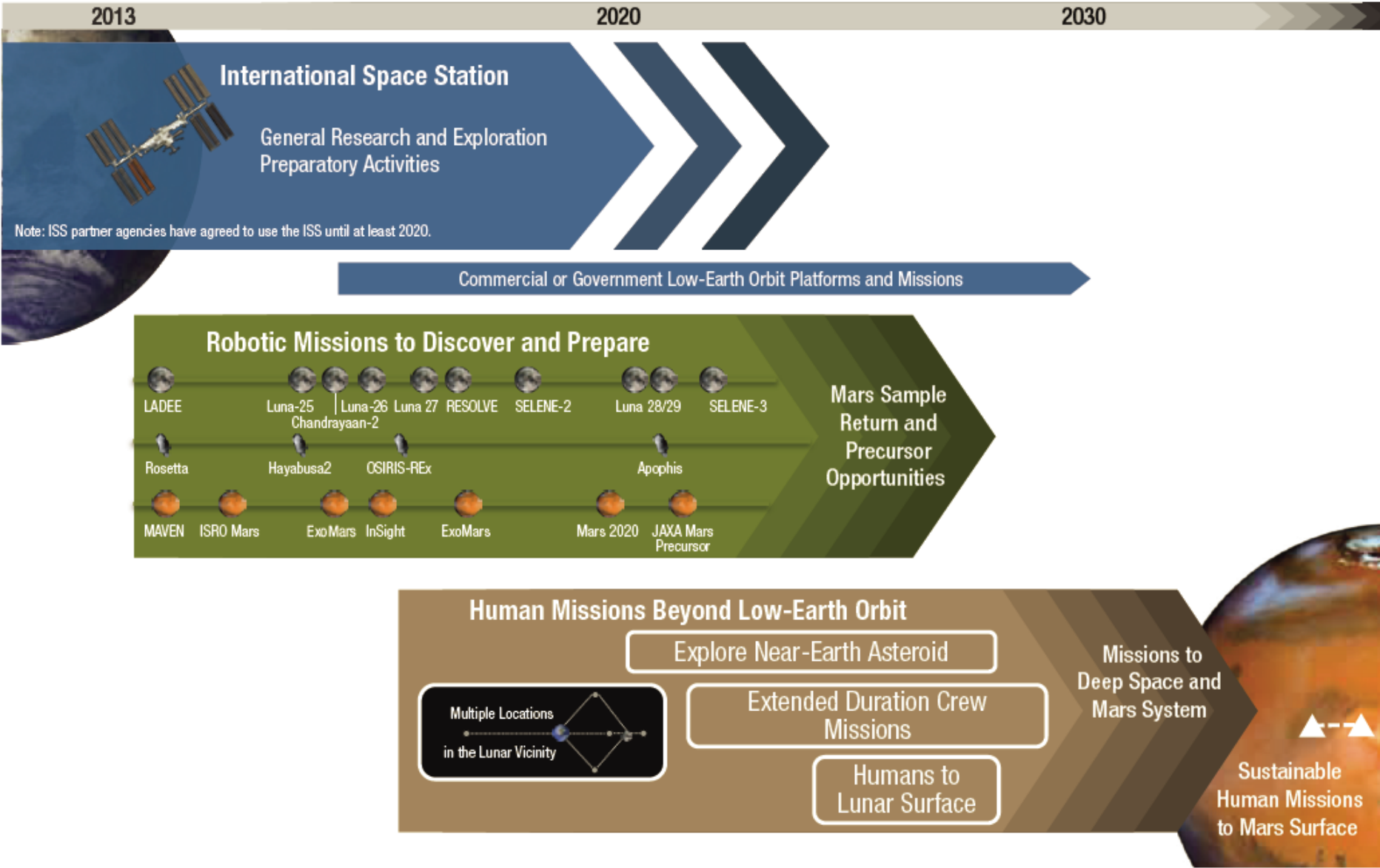




# From the GER Mission Scenario

- **Ultimate objective is Mars**
- **Significant precursor activities necessary to prepare required systems**
- **Several interim destinations are possible**
- **ISS role in shaping technical basis and managerial model**
- **Strong partnership between human and robotic exploration programs**
- **International partners are prepared for and require key mission critical roles**

# Global Exploration Roadmap



ARM  
TO  
MARS

Asteroid  
Redirect  
Mission

Martian  
Moons

Mars  
Surface

MOON  
TO  
MARS

Lunar  
Surface  
Sortie

Lunar  
Surface  
Outpost

Mars  
Surface

ENHANCED  
EXPLORATION

Earth  
Moon  
L2

Asteroid in  
Native  
Orbit

Lunar  
Surface  
Sortie

Lunar  
Surface  
Outpost

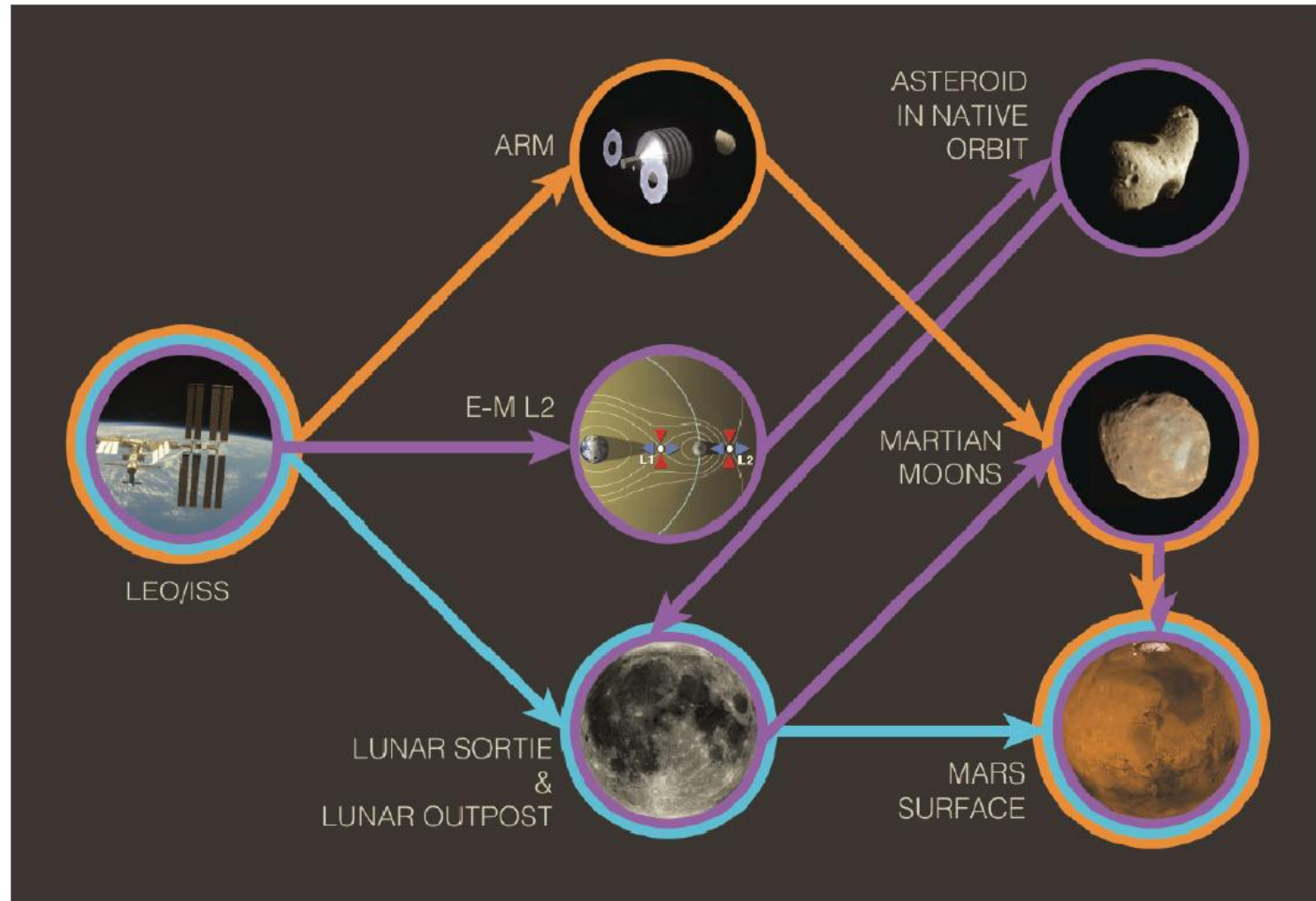
Martian  
Moons

Mars  
Surface

PATHWAY

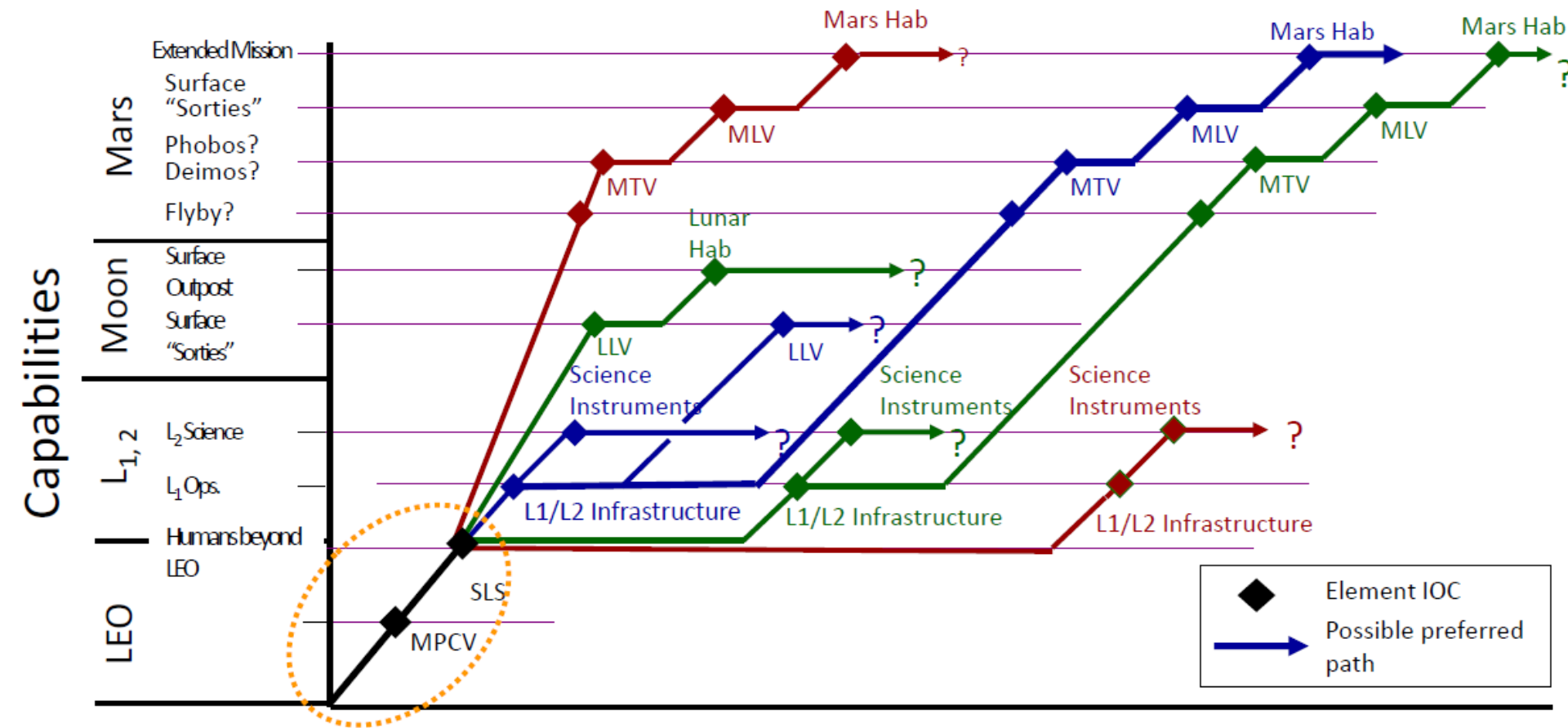
DESIGN REFERENCE MISSION (DRM)

## PATHWAY STEPPING STONE DESTINATIONS

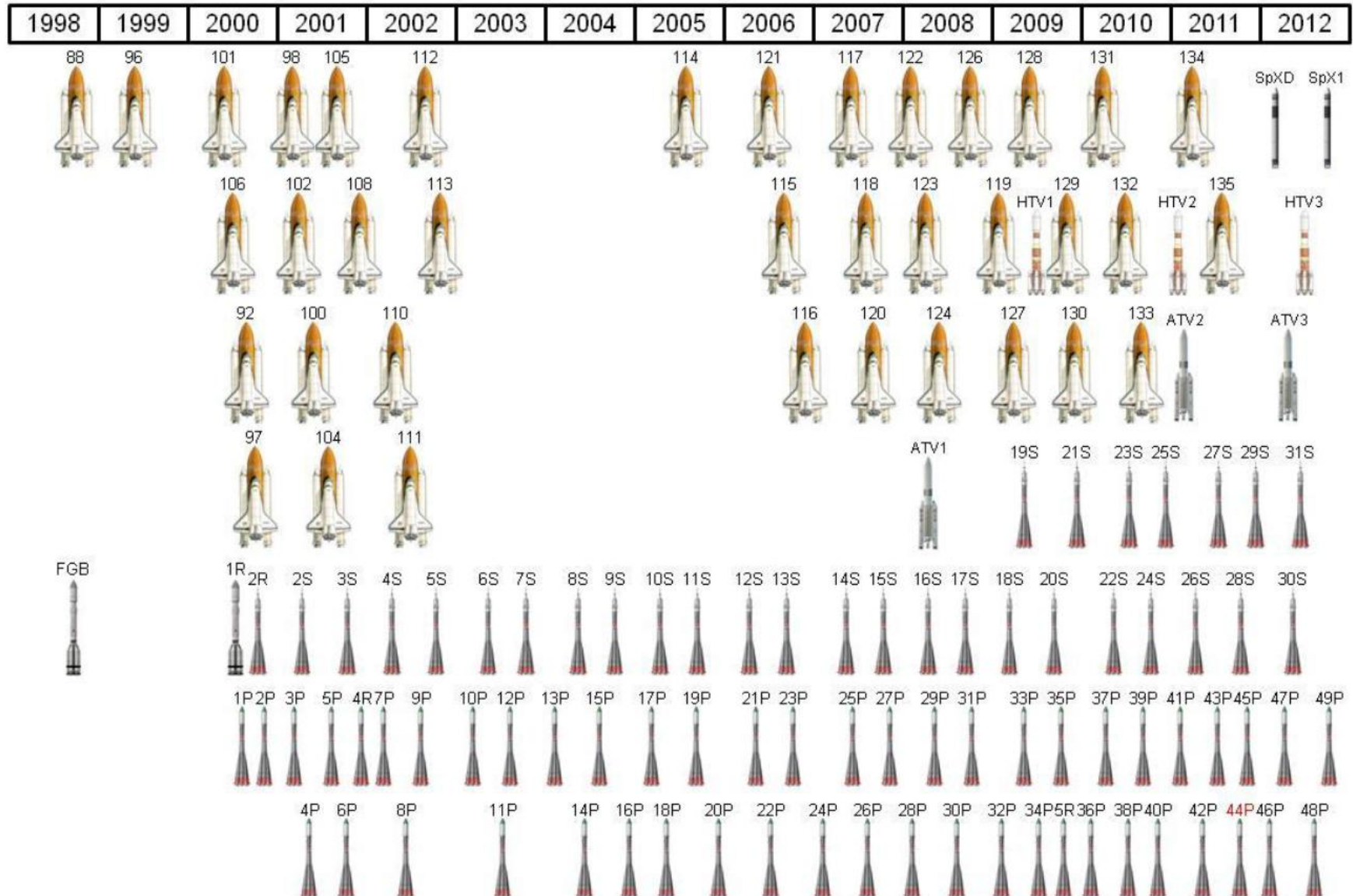




# Possible Strategy for Architecture Pathways



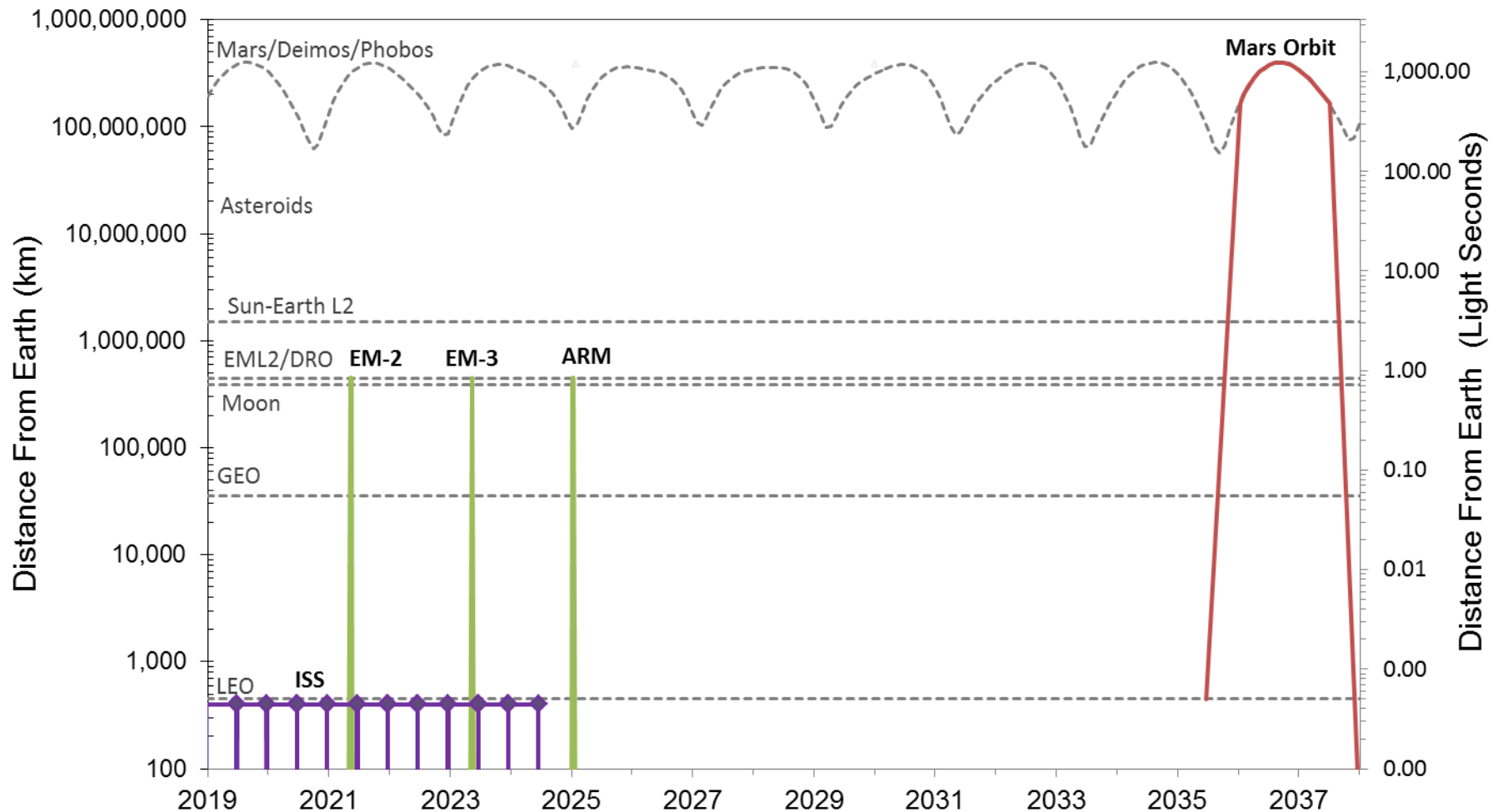
# ISS Assembly and Operations



# Mind the Gaps



## Current NASA Human Spaceflight plan





# The Future of Human Space Exploration

## *NASA's Building Blocks to Mars*

U.S. companies provide affordable access to low Earth orbit

Mastering the fundamentals aboard the International Space Station

Pushing the boundaries in cis-lunar space

Developing planetary independence by exploring Mars, its moons, and other deep space destinations

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule

*Missions: 6 to 12 months*  
*Return: hours*

*Missions: 1 month up to 12 months*  
*Return: days*

*Missions: 2 to 3 years*  
*Return: months*

Earth Reliant

Proving Ground

Earth Independent

# EVOLVABLE MARS CAMPAIGN

*A Pathways Approach to Exploration*



EARTH DEPENDENT

PROVING GROUND

EARTH INDEPENDENT



## THE TRADE SPACE

Across the Board

Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses



# The Next Step Beyond ISS

- **Crew tended habitat in cis-lunar space**
  - **Builds off of the Asteroid redirect mission and ISS**
    - **Allows for further study of gravity assist trajectory operations**
    - **Builds off of ISS life support with less earth support**
    - **Enables international partner and commercial lunar surface activities**
    - **Develops incremental risk management concepts to be developed and accepted**
    - **Exposure to galactic cosmic background radiation**
  - **Allows for Mars operational strategies to be developed**



# Introduction

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Space Exploration

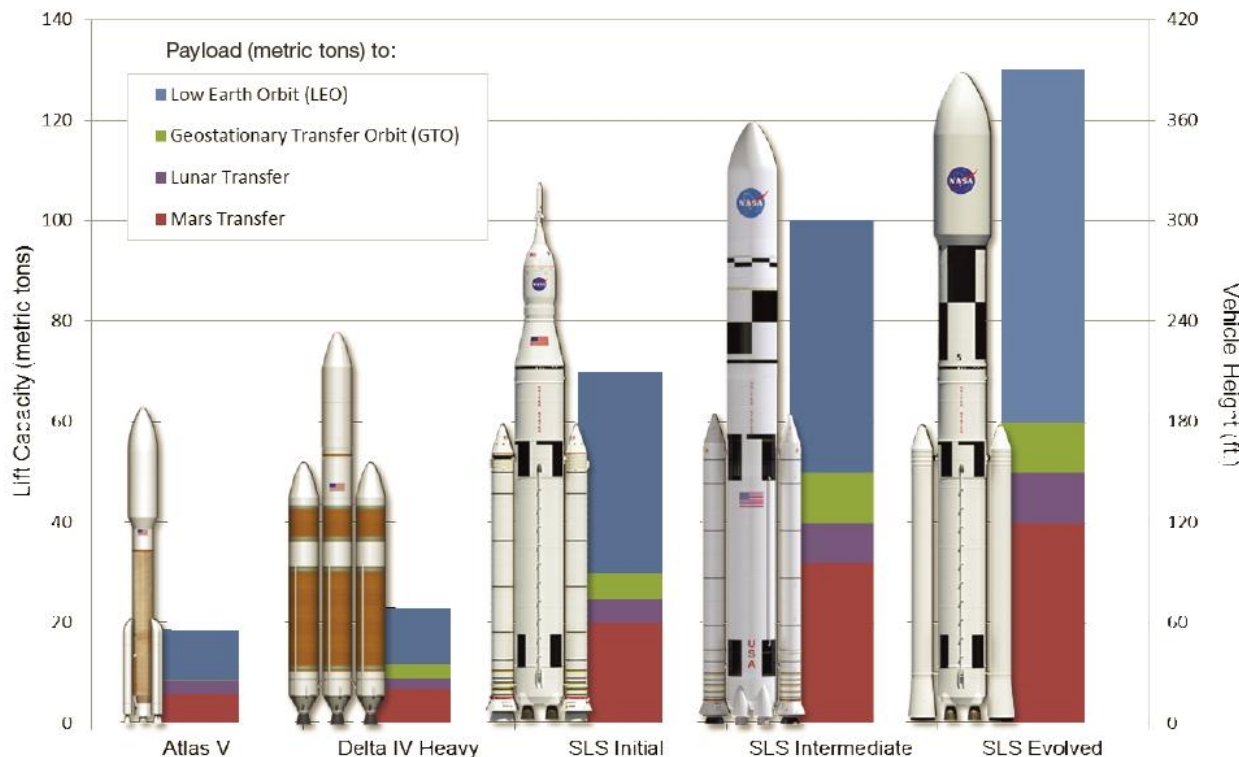


Space Launch System (SLS) is the most powerful rocket ever built and provides a critical heavy-lift launch capability enabling diverse deep space missions. The exploration class vehicle launches larger payloads farther in our solar system, faster than ever before.

# SLS Configurations and Capability

**SLS is the first rocket and launch system in history capable of powering humans, habitats and space systems beyond our moon and into deep space.**

**Launch Vehicle Lift Capabilities**

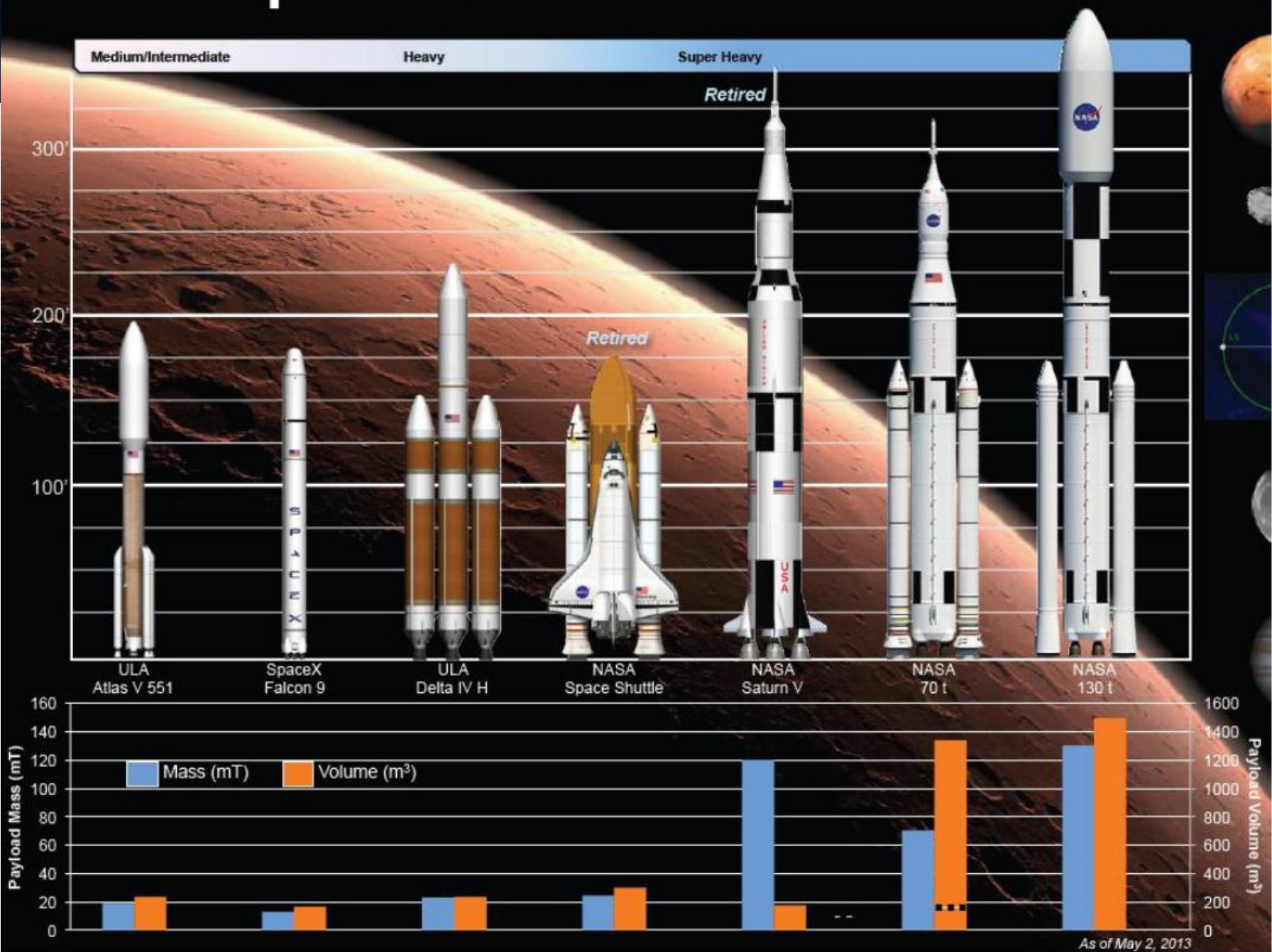


The vehicle's 5 m to 10 m fairing allows utilization of existing systems which reduces development risks, size limitations and costs. SLS lift capacity and superior performance shortens mission travel time.

Enhanced capabilities enable a myriad of missions including human exploration, planetary science, astrophysics, heliophysics, planetary defense and commercial space exploration endeavors.



# Most Capable U.S. Launch Vehicle

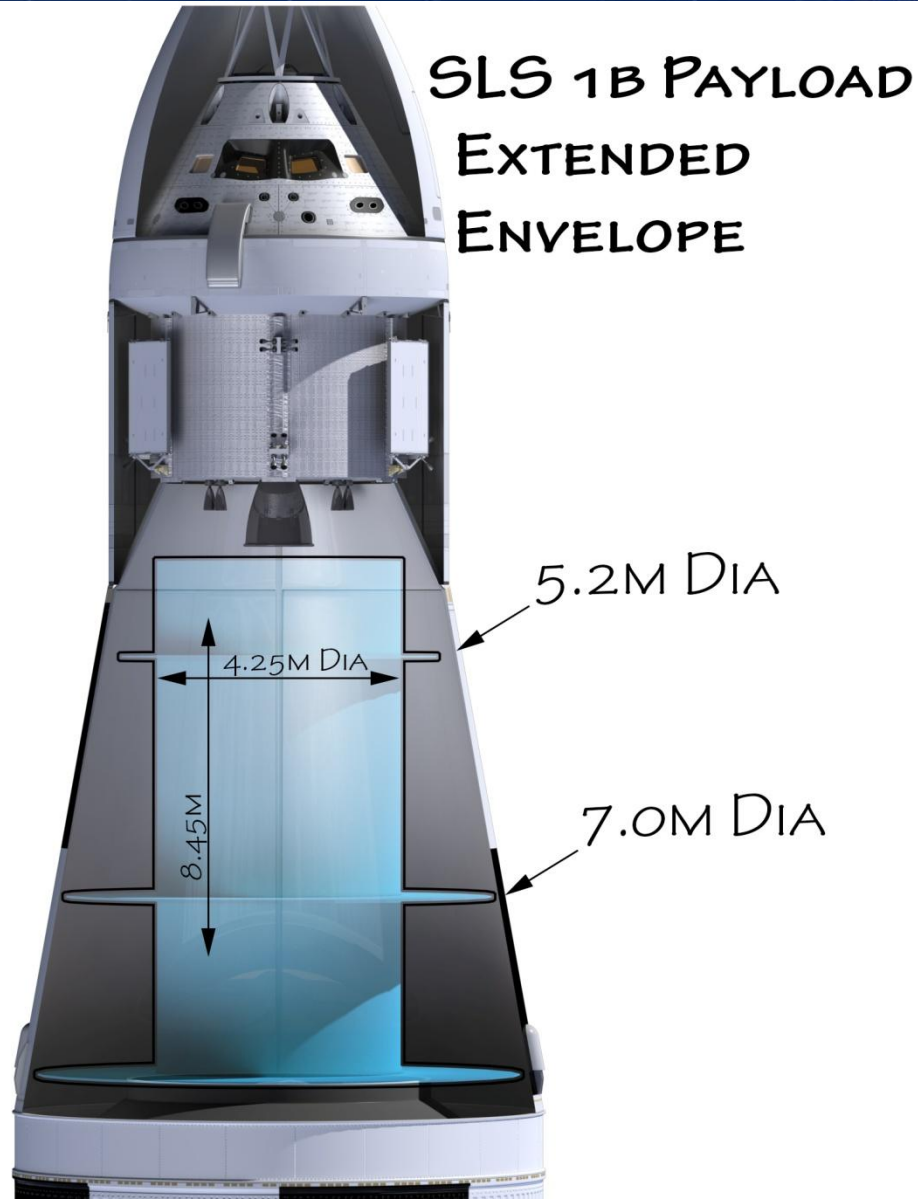




# Exploration Upper Stage (EUS)



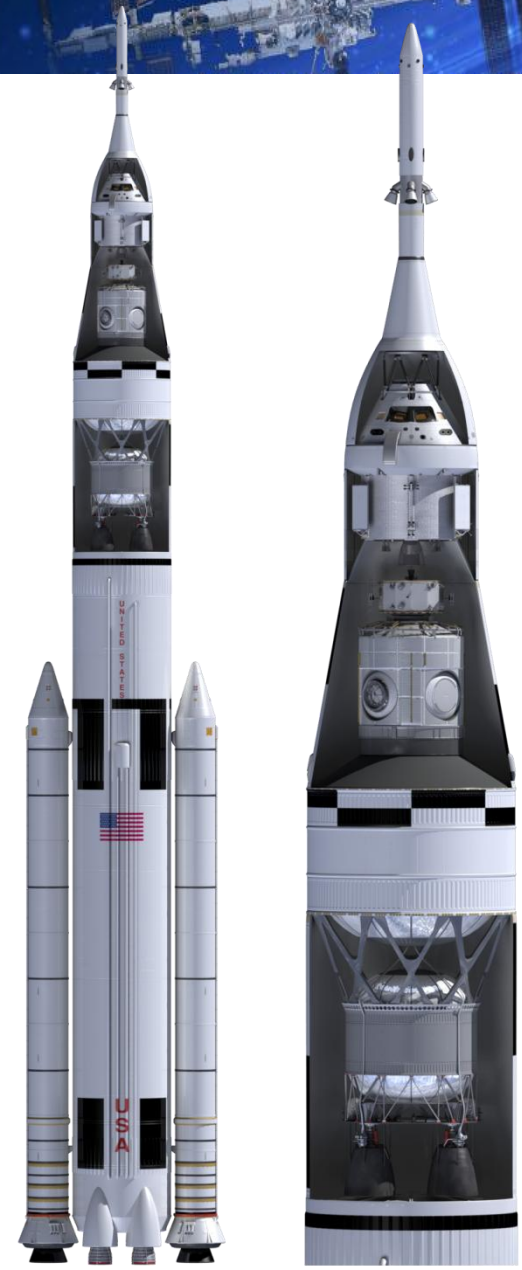
# SLS 1B Payload Capability



# EM-2: Orion with EAM to 71,000km DRO

## ■ Orion with EAM

- Exploration Augmentation Module (EAM)
  - Cygnus-based bus concept
    - Larger arrays
  - “Node-like” structure
- Current mission design assumes MSA2 & PAF are included in TLI mass
  - Orion docks to EAM after both separate
- Orion SM performs all maneuvers into DRO while docked to EAM
- EAM performs station keeping after Orion departure





# EM-2: Orion with EAM to 71,000km DRO

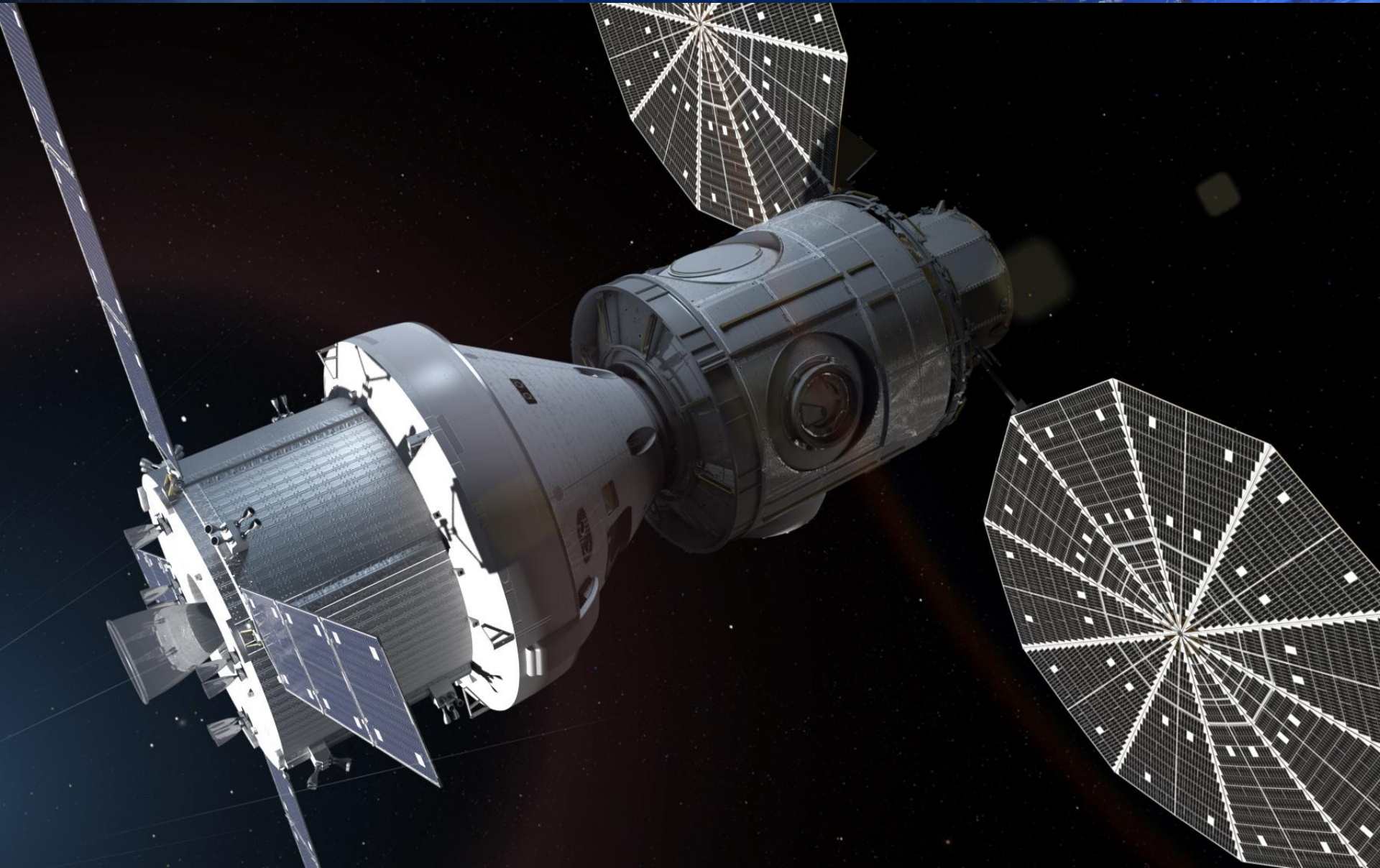
## •TLI performance:

- $dV = 2,707 \text{ m/s}$
- EUS propellant used = 52,139 kg
  - Margin of 3,874.3 kg (56,013.3 – 52,139)
- TLI performed assuming MSA2 & PAF adapter mass
- Jettison of EUS, PAF, MSA2 performed after TLI complete
- Payload mass delivered:
  - Orion
    - CM @ 10,387 kg
    - SM Inert @ 6,857.6 kg
    - SM Prop @ 8,602.4 kg
  - Payload
    - Assumed a **10,000 kg** EAM payload (total)
- Fly-By Target (includes 10t payload):
  - Orion Impulsive
  - $dV$ : 166 m/s
  - Prop Used: 1,548.4 kg
- DRO Insertion at 71,000 km (includes 10t payload)
  - Orion Impulsive
  - $dV$ : 120 m/s
  - Prop Used: 1,072.8 kg

SLS Performance suggests that EAM mass could be up to 12,000Kg

# Orion docked to EAM

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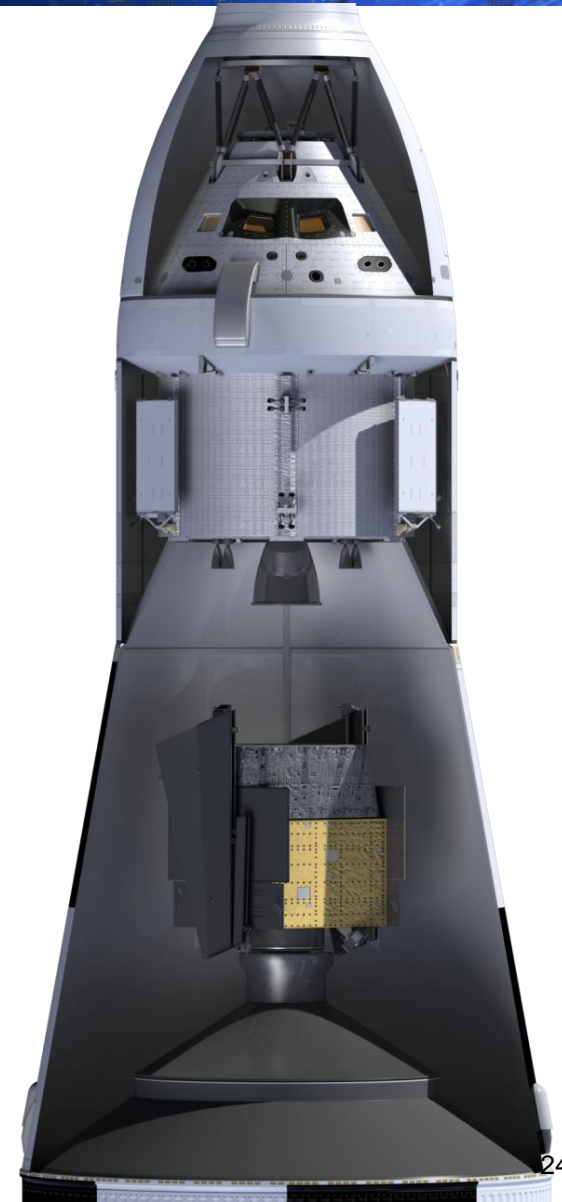
# Comparison of Orion and EAM

Capability	Orion	EAM + Orion
<b>Exobody Interaction</b> <ul style="list-style-type: none"> <li>Characterize geology and topography at destinations and collect samples</li> <li>Test tools and technologies to extract, process, and utilize resources</li> </ul>	✓	✓
<b>Science</b> <ul style="list-style-type: none"> <li>Earth observation, heliophysics, and astrophysics and other applied research</li> </ul>	✓	✓
<b>Crew Health</b> <ul style="list-style-type: none"> <li>Evaluate human health and risk mitigation in the deep space environment</li> <li>Test radiation countermeasures and mitigation technologies and strategies</li> <li>Monitor and predict radiation</li> </ul>	✓	✓
<b>Spacecraft Systems and Operations</b> <ul style="list-style-type: none"> <li>Space power generation and storage</li> <li>High-performance mobility and extravehicular activity capabilities</li> <li>Autonomous robots to supplement crew activities</li> <li>Advanced in-space propulsion capabilities</li> <li>Automated rendezvous and docking and on-orbit assembly capabilities</li> <li>Space communications and navigation capabilities</li> <li>Protocols for deep space operations at a large distance from Earth</li> </ul>	Partial	✓
<b>Cooperation</b> <ul style="list-style-type: none"> <li>Opportunities for integrating commercial elements</li> <li>Opportunities for international space agency cooperation</li> </ul>		✓
<b>Extend Orion mission duration in translunar space</b>		✓
<b>Long duration habitability in deep space</b>		✓
<b>Provide a local abort destination for Orion missions</b>		✓
<b>Extensible architecture for future exploration missions</b>		✓



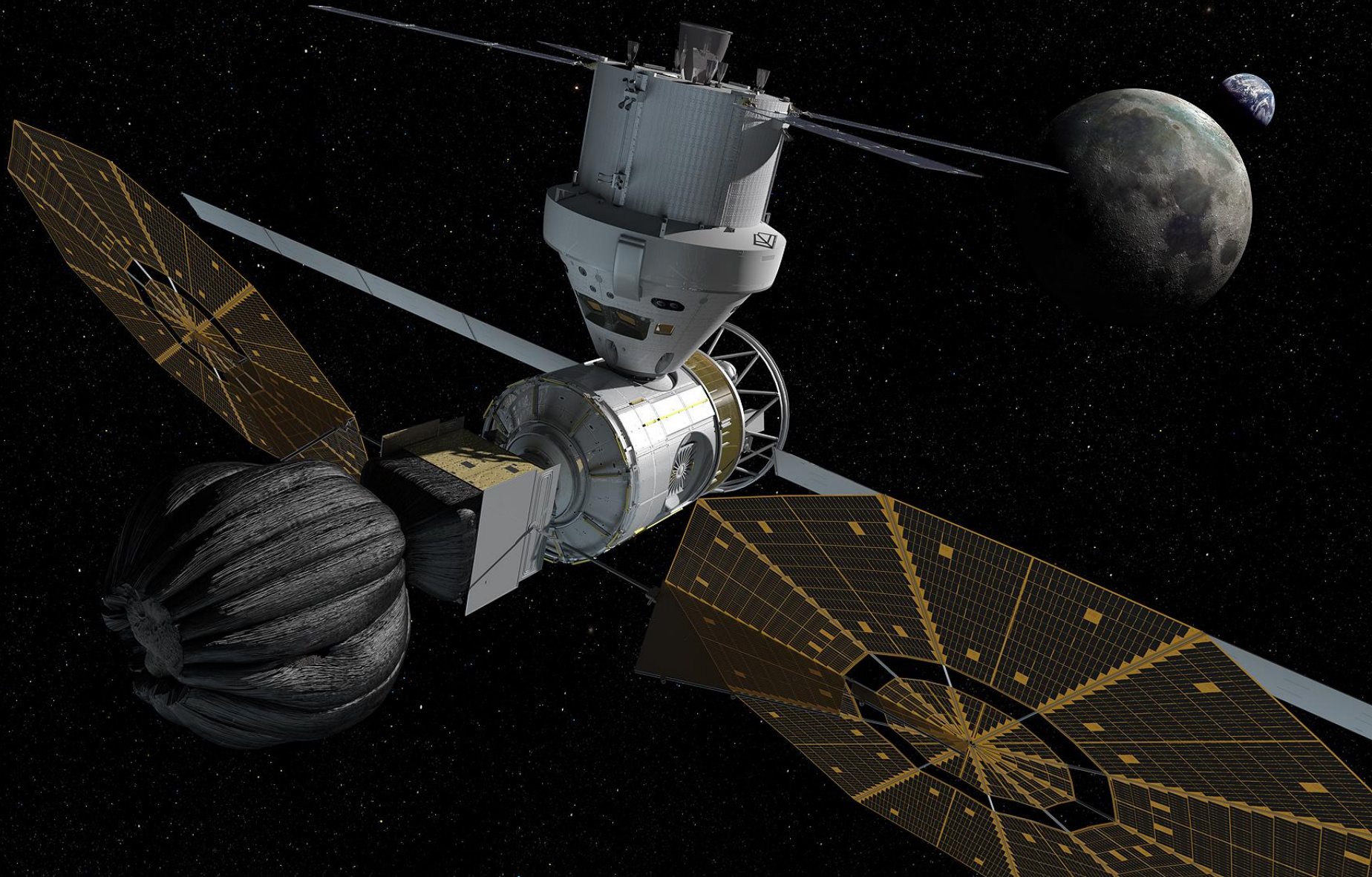
# EM-3: Orion with Asteroid Retrieval Vehicle

- **Orion with ARV**
  - Asteroid Retrieval vehicle (ARV)
    - Lunar fly-by direct to Asteroid
    - Ballistic trajectory to asteroid
  - Orion mission to EAM
    - Longer duration stay (2.5 revs-35 days)?
    - Preps for next mission
      - Lunar sample return?



# Mission concept including Gateway

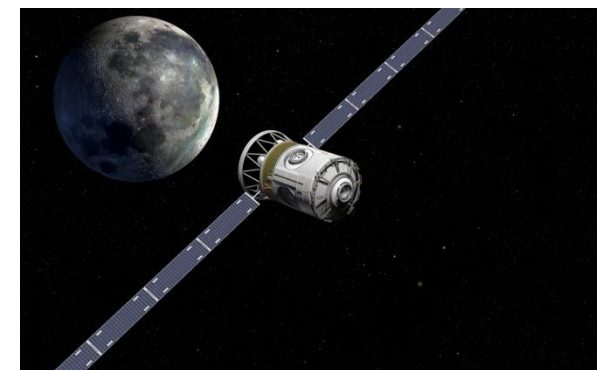
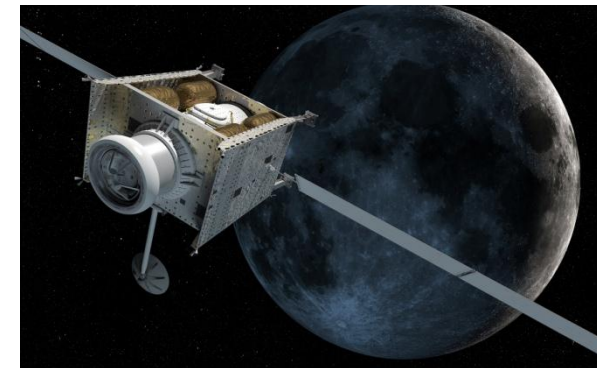
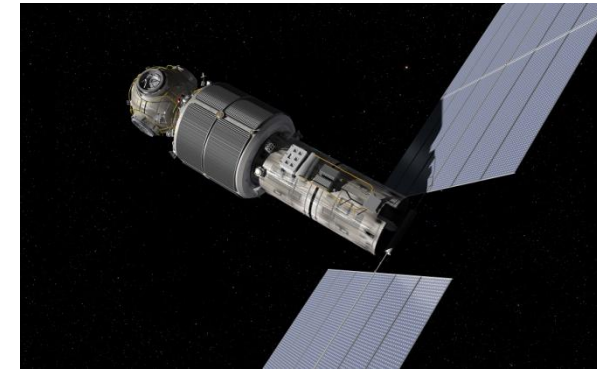
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# Asteroid Exploration Module

- Crew operations at a redirected asteroid could be significantly enhanced by providing additional systems and EVA capabilities beyond those available from Orion only missions.
- Placing an Asteroid Exploration Module (AEM) at the redirected asteroid would :
  - Extend mission duration – Reduce EVA and consumables mass requirements on Orion
  - Increase capability – Supply additional EVA functions and crew volume
  - Reduce risk - Provide an abort location for Orion





# Risk Reduction for Exploration

- **EAM increases science return of the Asteroid Redirect Mission**
- **EAM demonstrates many core capabilities needed for deep space missions**
  - Electric propulsion
  - EVA
  - Deep space navigation and communications
  - Long duration operations beyond low earth orbit
  - Commercial/international interaction
  - Long duration radiation countermeasures and mitigation
- **EAM benefits Exploration as a residual asset**

# EM-4: Orion with Robotic Lander

## ■ Orion with Lander

Lander derived from Morpheus

- Lander injects into a lunar phasing orbit
- Target Schrödinger Basin on Lunar farside (example)
- Phase to time landing at the beginning of the lunar day
- Lander Payload: Ascent Vehicle and option for Rover
- Sample returned to crew at the end of the Lunar day

## — Orion mission to EAM

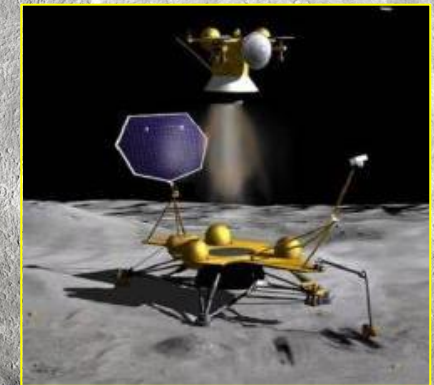
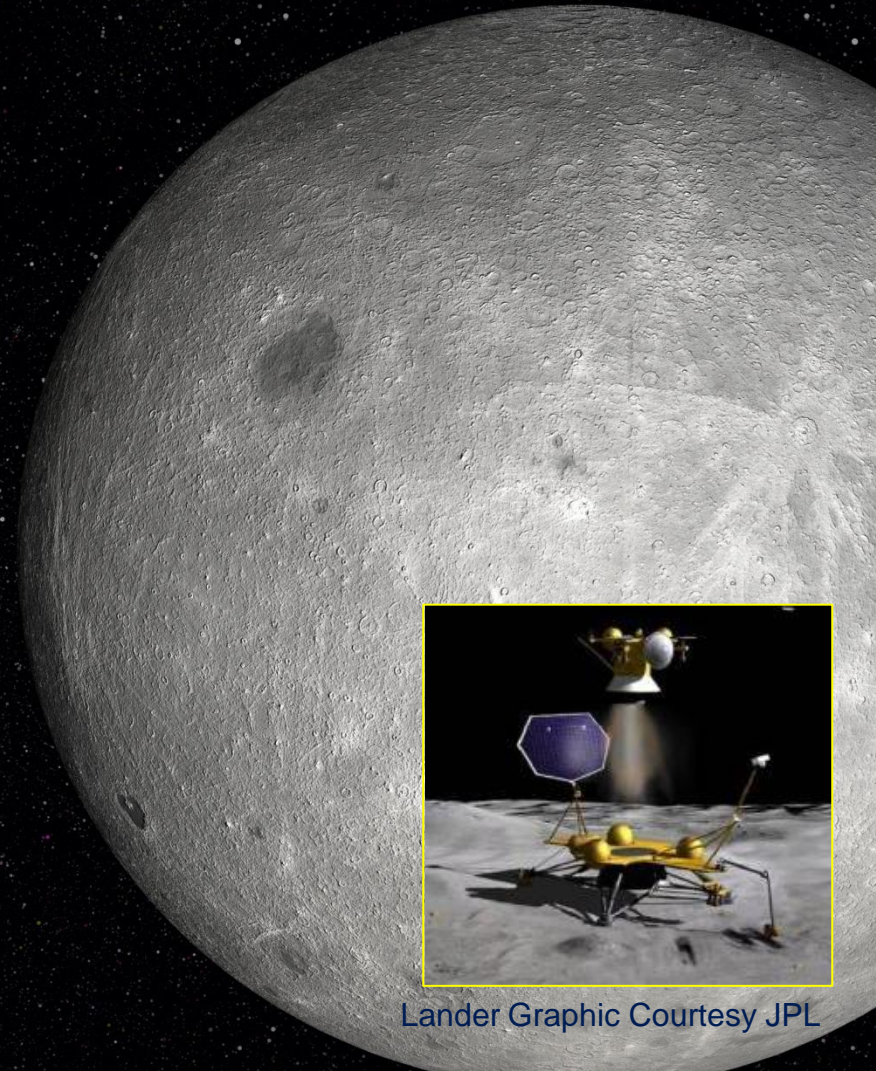
- Longer duration stay (3.5 revs-50 days)?
- Farside comm considerations
- Several options for sample retrieval:
  - OSCAR integrated into EAM
  - Grapple arm on EAM; EVA sample retrieval
  - NDS for ascent vehicle; EVA sample retrieval
  - NDS ascent (pressurized); IVA sample retrieval





# Moonrise Mission

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Lander Graphic Courtesy JPL



# Sample Return Lander



## Lander Summary Table

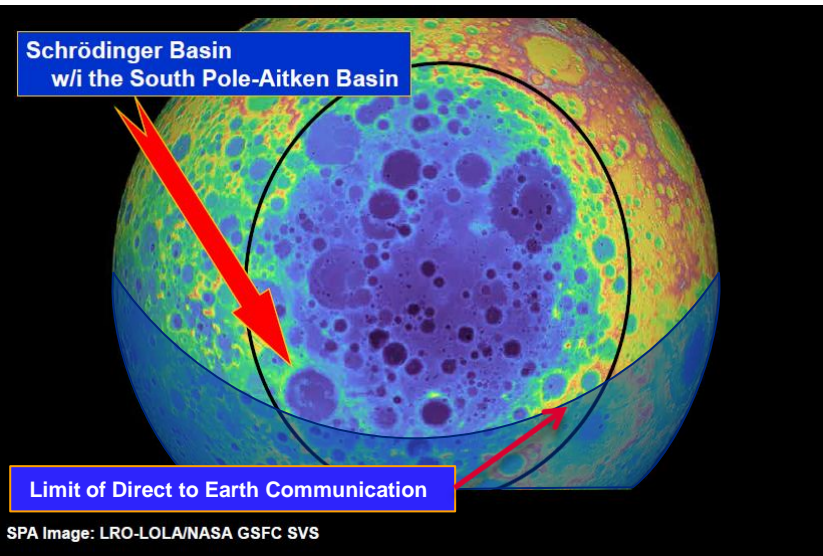
Description	Morpheus	Hosted Lander
Engine Thrust	22,000 N	22,000 N
Propellant	LOX/CH4	LOX/CH4
Specific Impulse (Isp)	321	321
Propellant Mass	2,900 kg	5,900 kg
Dry Mass	1,100 kg	2,600 kg
Payload	500 kg	1,500 kg
Diameter	3.7 m	5.5 m
Height	3.7 m	5.5 m
Total Est. Mass	4,500 kg	10,000 kg

# Sample Return Example – Schrödinger Crater



Image Courtesy of NASA – Clementine mission

- Why Schrödinger?
  - Large Impact Crater Within South Pole-Aitken Basin
    - Lat: 75.0°S, Long: 132.4°E, Main ring diam.: 320 km, Depth: 4.8 km
  - Sample return from SPA high priority from 2012 NRC Decadal Survey
  - Meets many goals of NRC 2007 Study
  - Access to Amundsen and Shackelton
  - ISRU Potential
    - Lunar regolith
    - Pyroclastic deposits
    - Polar Volatiles?
  - Many other prospective landing sites
    - Ex: 50 Constellation regions of interest
    - Recognition that target would be selected with community input



# Sample Return Example – Schrödinger Crater con't

Payload

Lander with Ascent Vehicle

Long lived teleoperated prospecting rover with sample caching mechanism  
(Find, Characterize, Document, Return Samples)

Model payload

Caching mechanism (modeled after Mars 2020)

Drill

Mineralogy

X-Ray Diffraction

Multispectral (UV-VIS-NIR) reflectance spectrometer

Elemental Abundance

Gamma-Ray spectrometer

Laser-induced Breakdown Spectroscopy (LIBS)

Lunar Environment

Magnetometer

Handlens camera

Electrical charge detection

Ability to traverse beyond Schrödinger when primary mission complete

Amundsen

Shackleton

Rover could be modeled after Curiosity

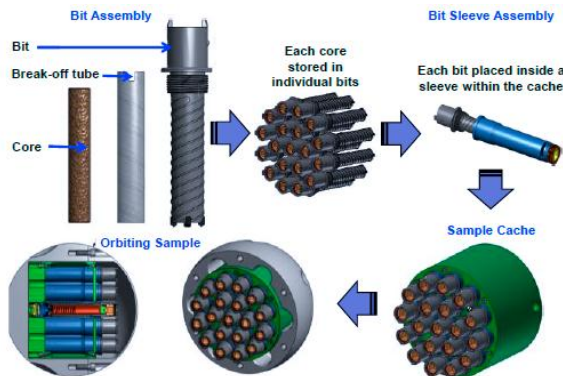


Image Courtesy of Zacny– 2013

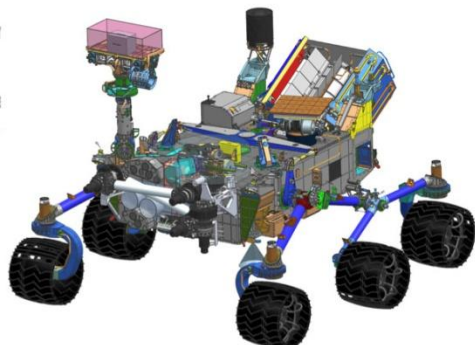
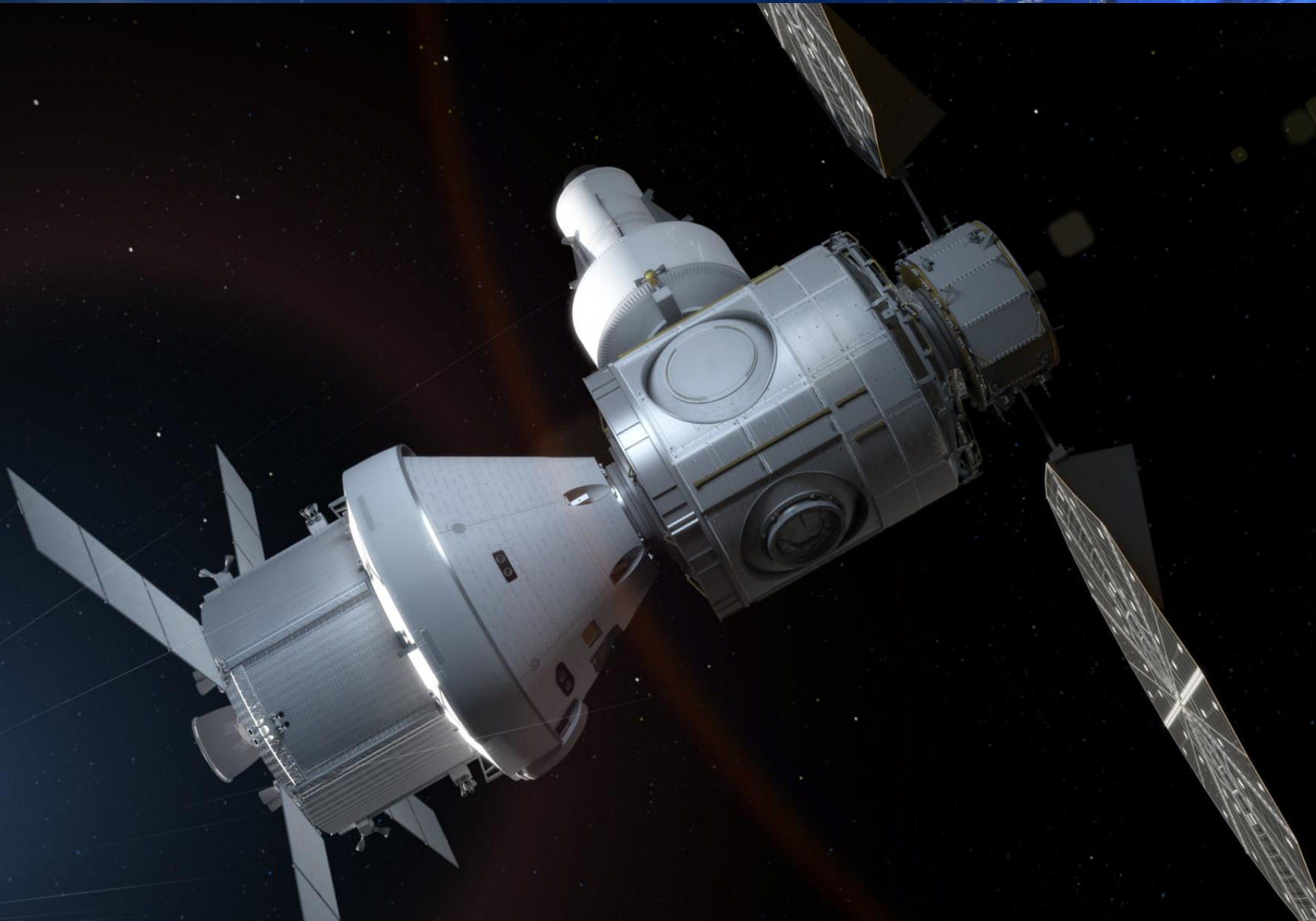


Image Courtesy of NASA



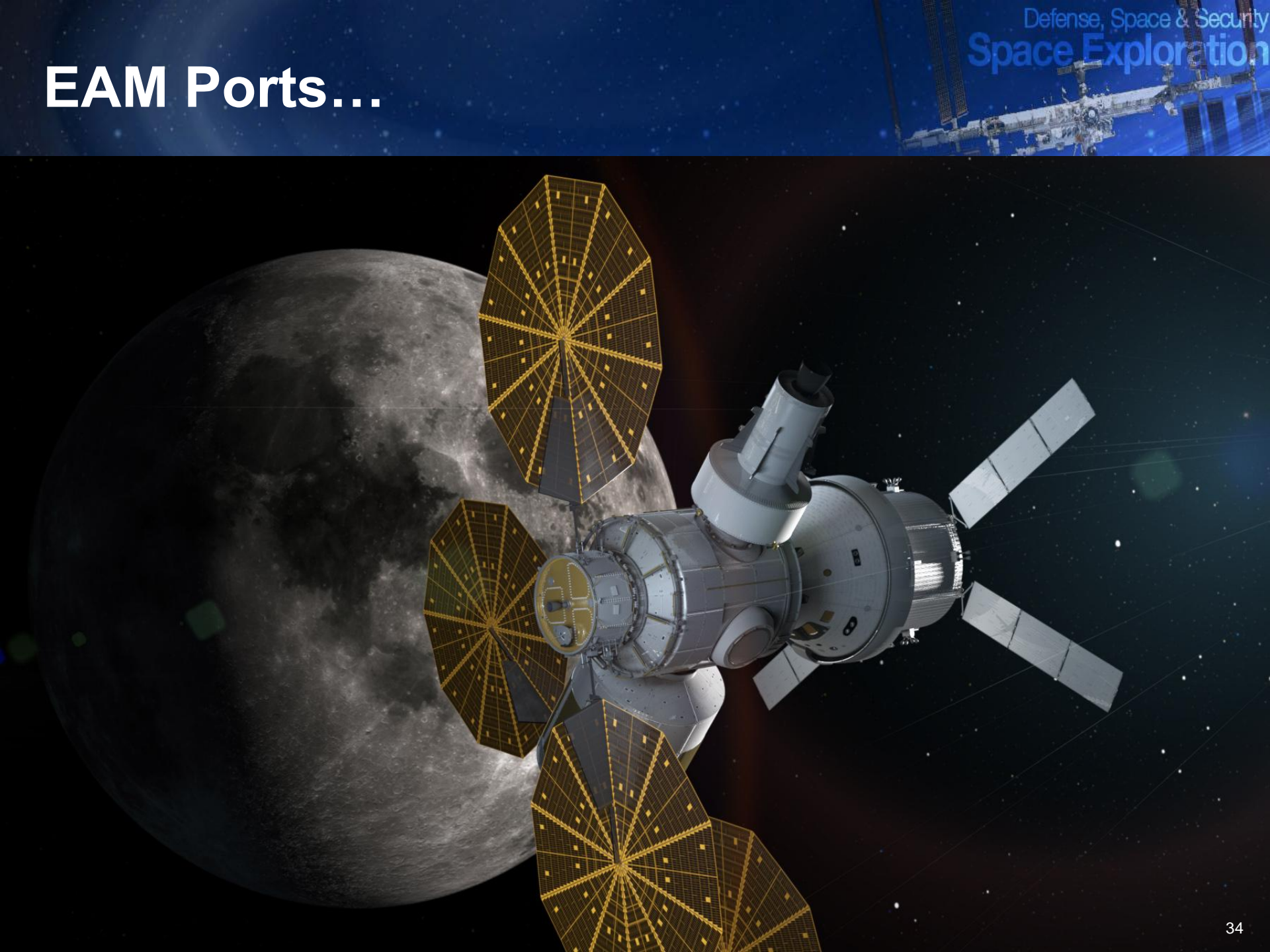
# Orion docked to EAM

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# EAM Ports...

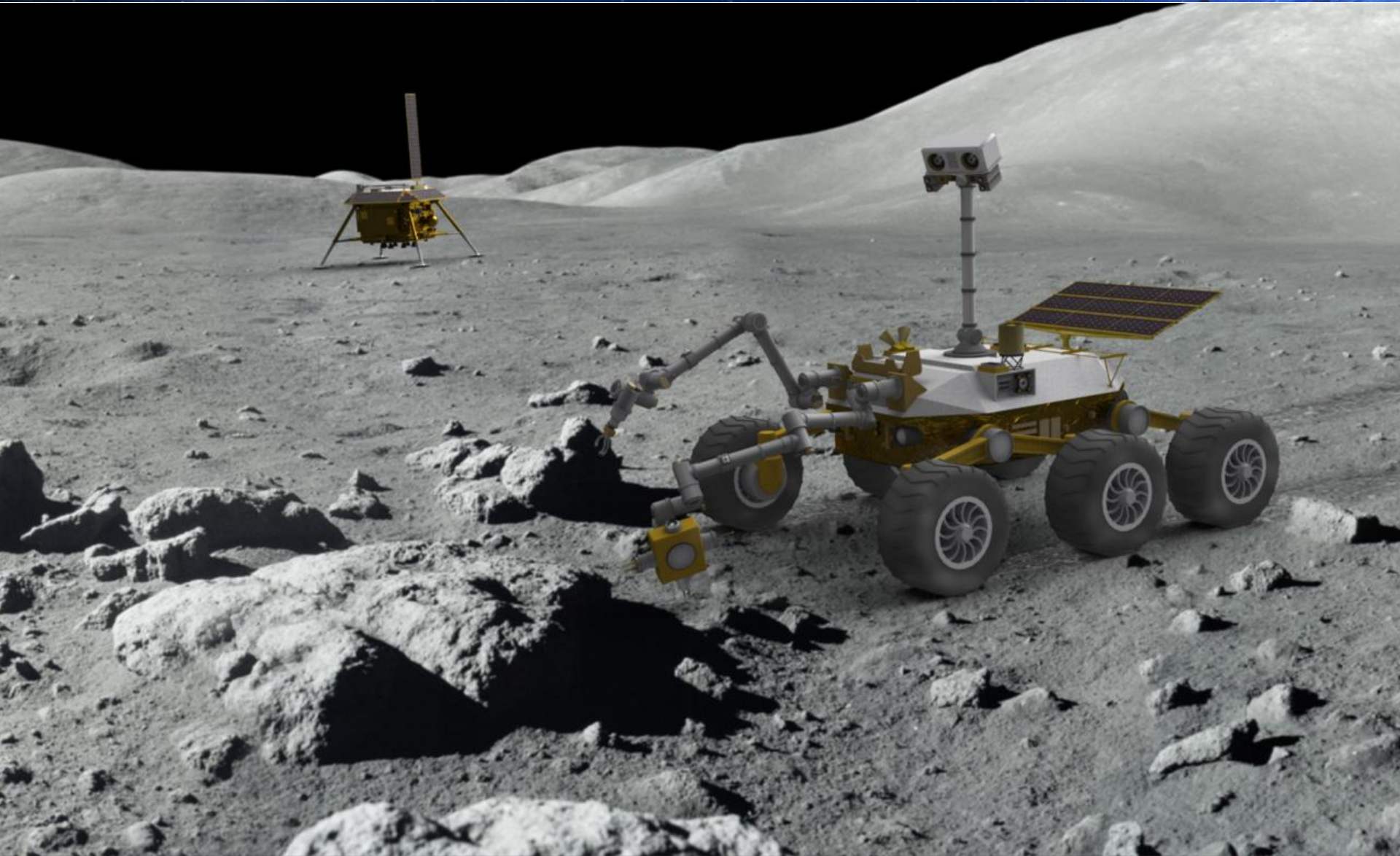
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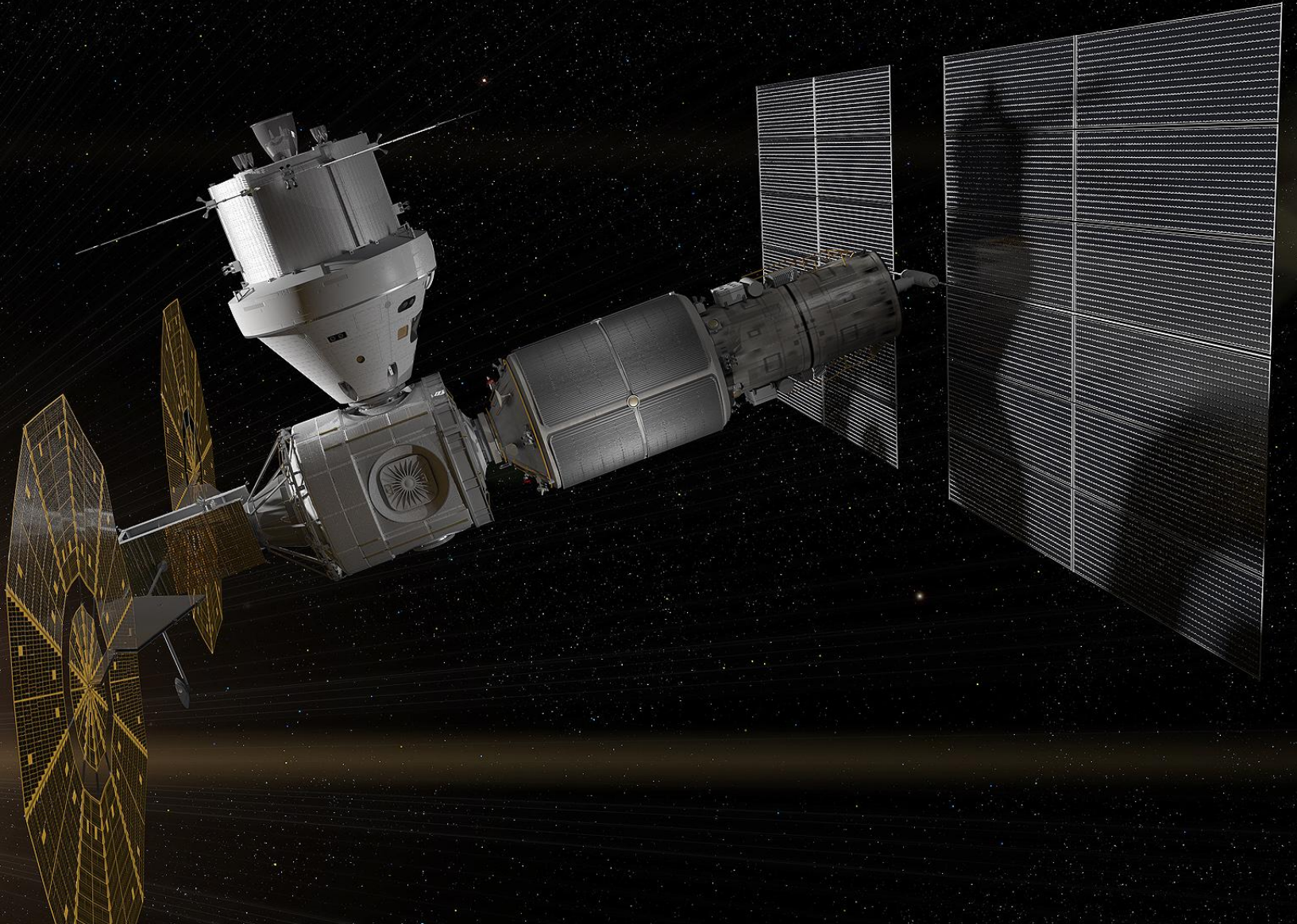






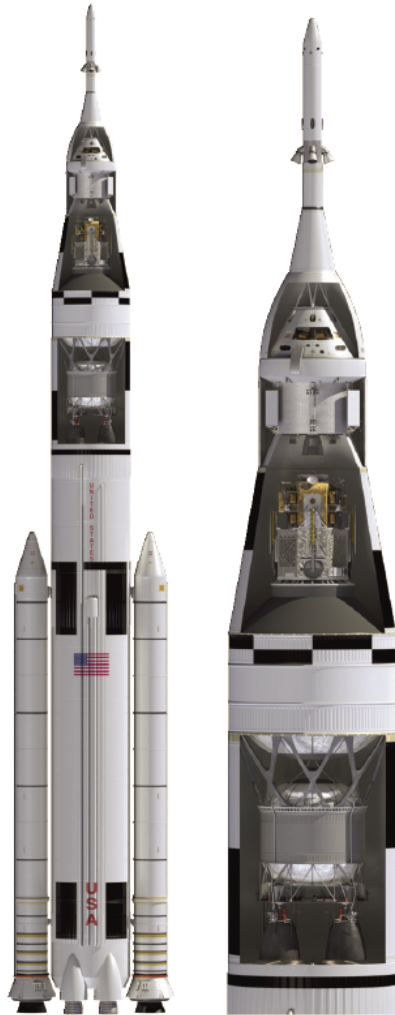


# Evolved gateway with SPM





# Lunar Surface Mission



## Lunar Surface Mission

### Mission Objective

Launch astronauts and a reusable lunar lander to the moon's surface

### Mission Rationale

Unlike Earth, the moon remains largely unchanged since the formation of the solar system. Through study of our only natural satellite, scientists can look billions of years into the past for geologic clues while engineers can test systems necessary for future Mars missions. Lunar exploration challenges strengthen international partnerships critical to ambitious deep space endeavors.

### SLS Capabilities

SLS enables human return to the moon. The intermediate SLS capability allows both crew and cargo to fly to translunar orbit at the same time which will simplify mission design and reduce launch costs.



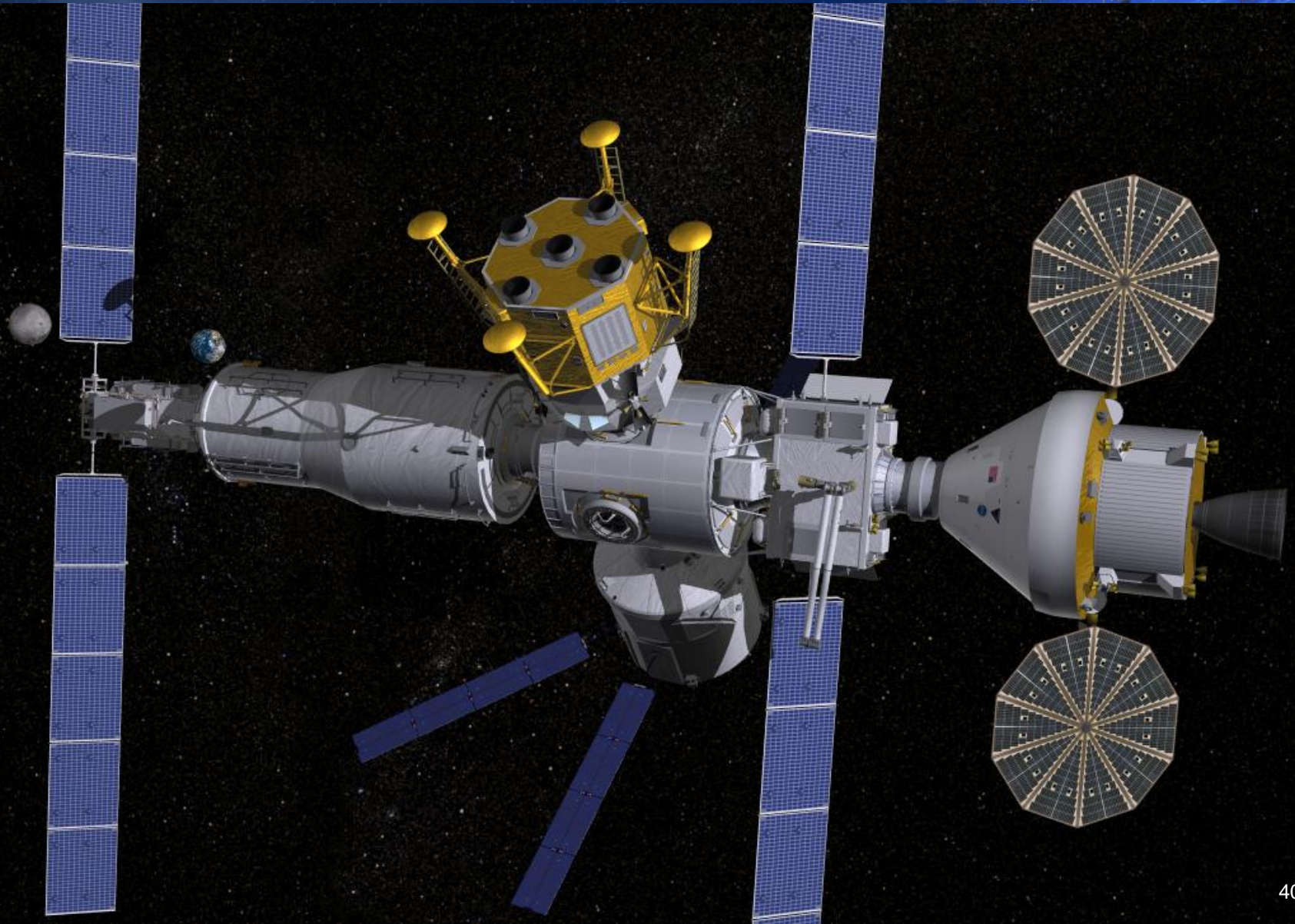
# Refueling Tanker





# Platform with Lunar Lander System

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# On the Moon

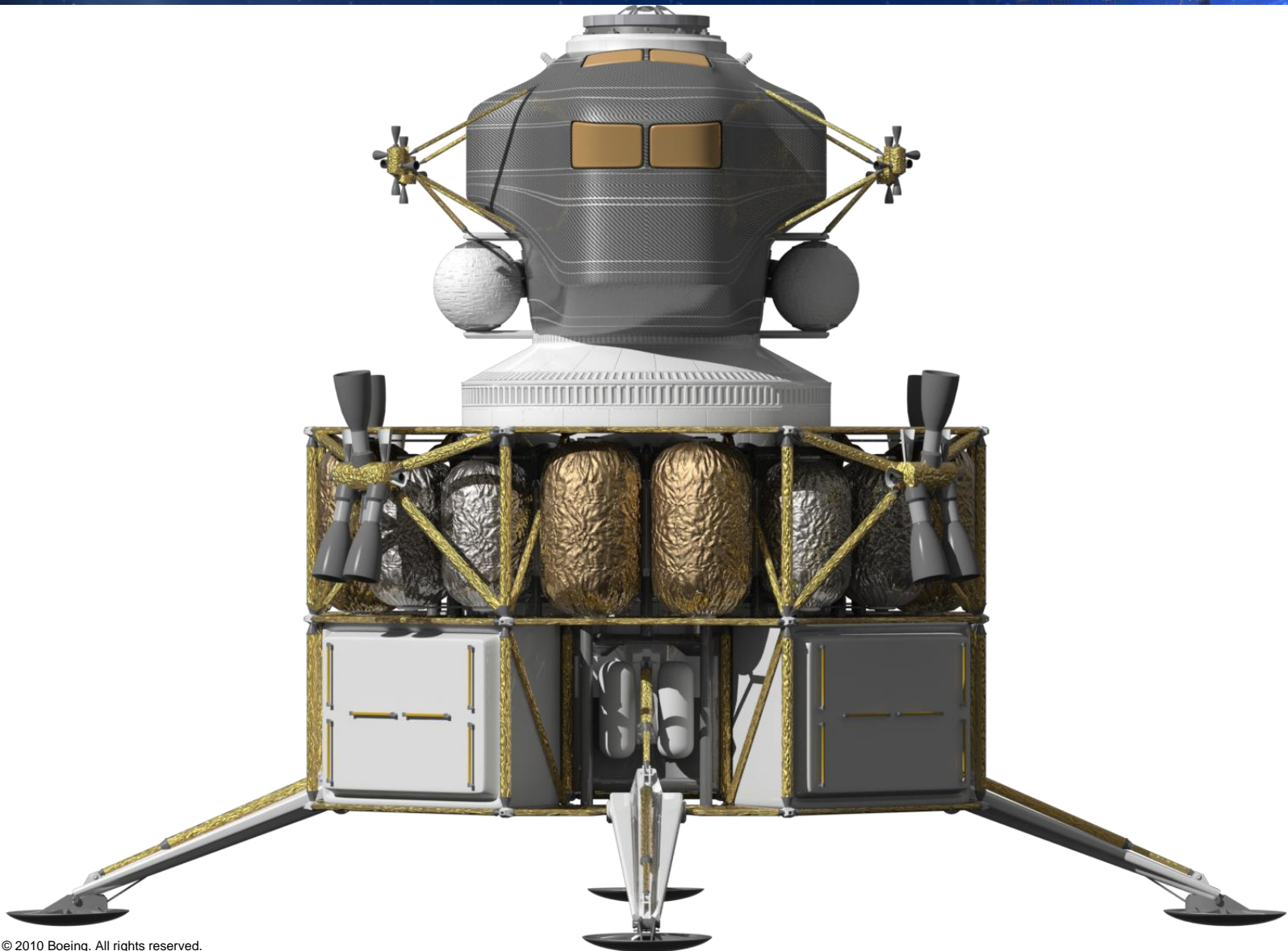
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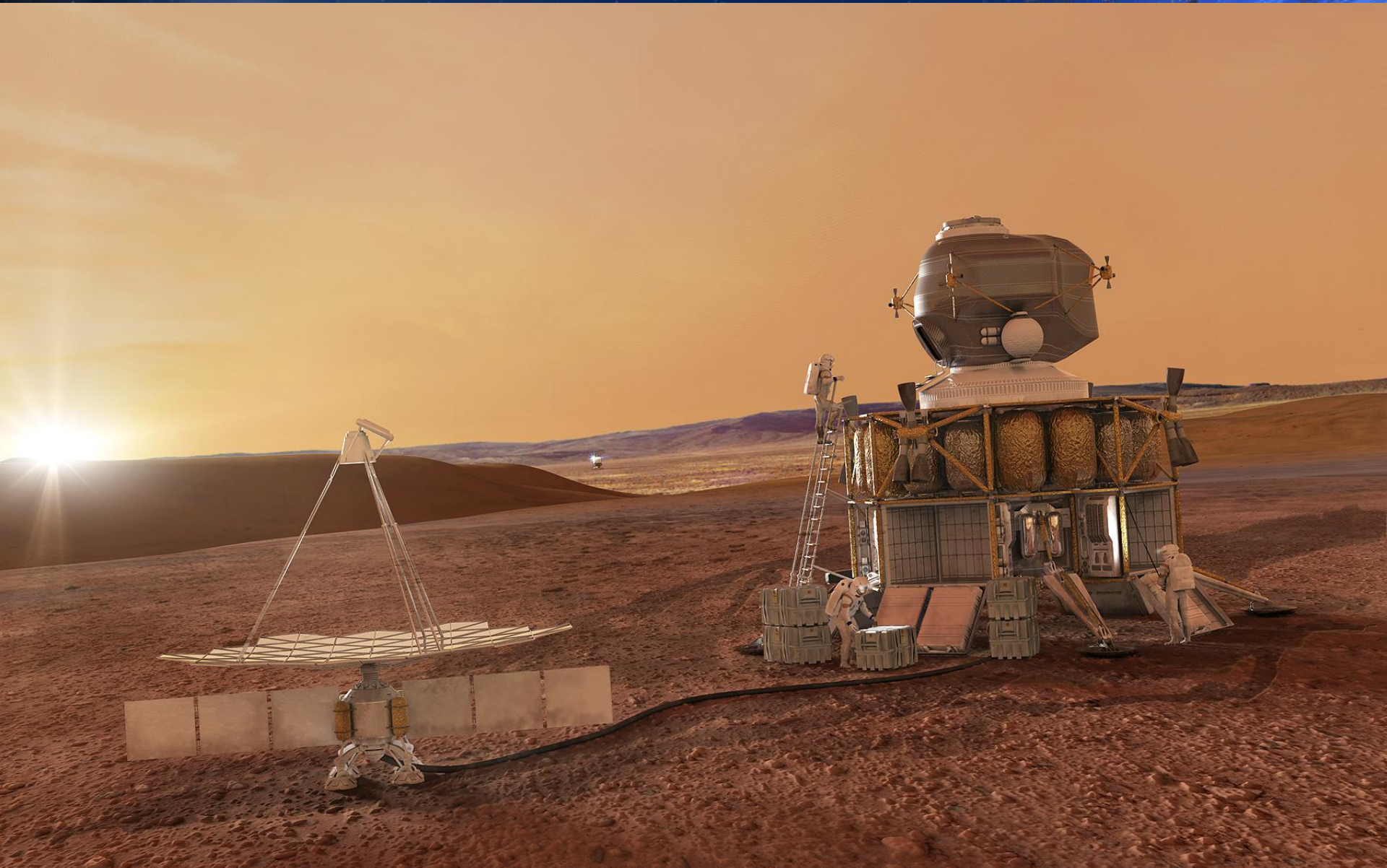
# Reusable Lander

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# On Mars

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# Deep Space Habitat: Bigelow BA 330



## Deep Space Habitat: Bigelow BA 330

### Mission Objective

Deliver expandable BA 330 module to cislunar space

### Mission Rationale

SLS supports commercial launch requirements and operations enabling a deep space human presence while extending Orion mission duration. The BA 330 is a stand-alone, self-sufficient module with crew support necessary to sustain long duration human habitation and may serve as a base element for future expansion. It can house up to six people on a long-term basis.

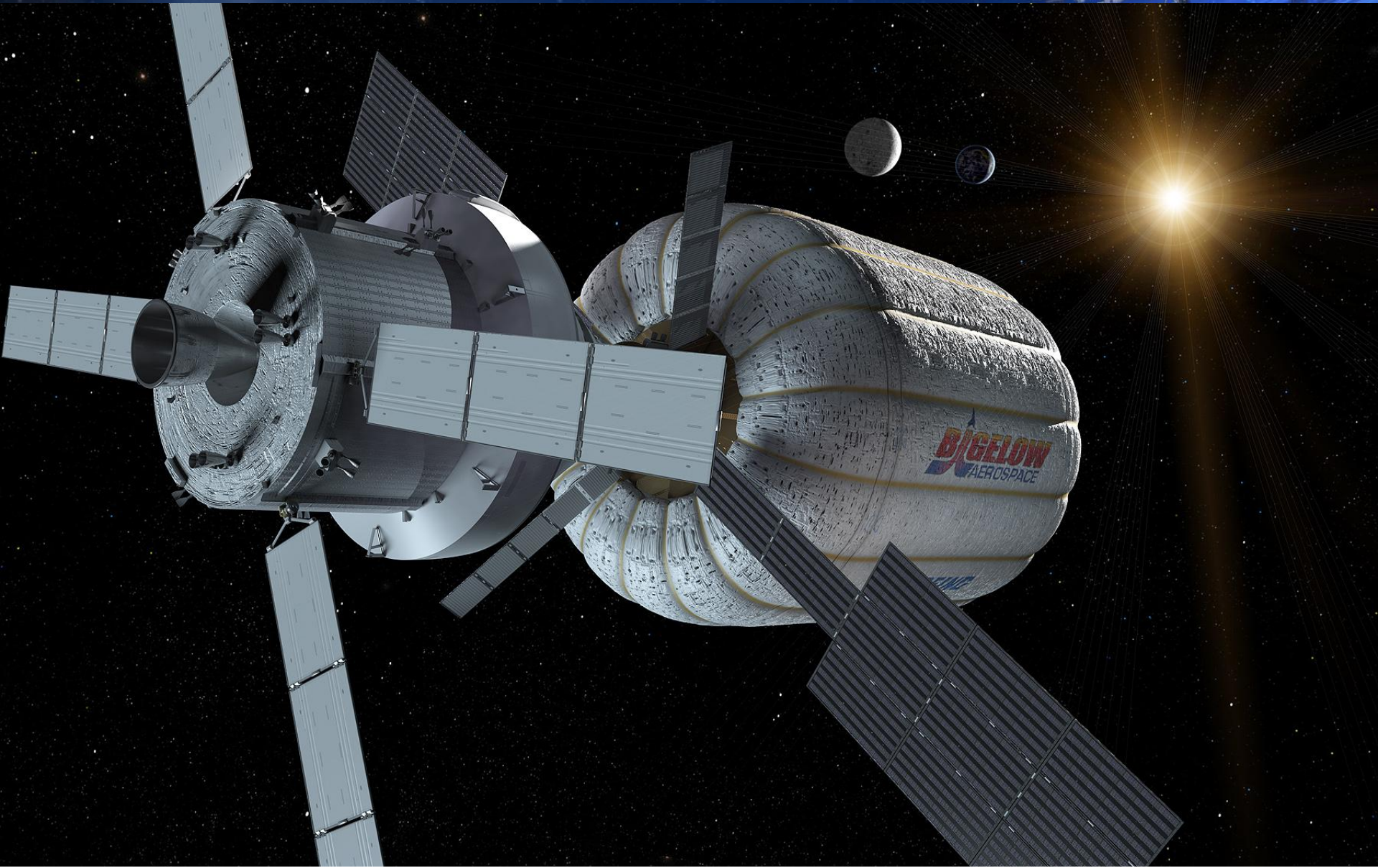
### SLS Capabilities

SLS is the only launch vehicle capable of delivering the BA 330 to EML2. The heavy-lift vehicle will transport the habitation module beyond the moon and back to cislunar space via a low-energy transfer that reduces required propellant mass. SLS mass margin allows additional consumables, radiation protection or a secondary payload.



# Bigelow Deep Space Habitat Deployed

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# International Cooperation



- ISS has established a firm basis for a vibrant exploration program with a proven management model and proven existing designs
- A Deep Space capability based on ISS technology provides flexibility and is an enabling capability for key cost-reducing strategies:
  - Mobility within the libration system
  - Reuse of expensive spaceflight hardware
  - Base for assembly of complex, deep space mission systems
- International collaboration has been proven effective on ISS and could be improved and expanded for exploration
  - Embrace the International Space Exploration Coordination Group (ISECG) Global Exploration Roadmap (GER)
  - Apply the lessons learned from the International Space Station program and the experiences of the current partnership
  - Strong coordinated support from the associated transportation programs (Shuttle, Soyuz, Arianne, H2B)
  - International partnership with strong political support
  - Adequate funding to accomplish the objective
  - Agreements on hardware/software interface and construction standards



# Questions?

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